Segmentation in large-scale cellular electron microscopy with deep learning: A literature survey

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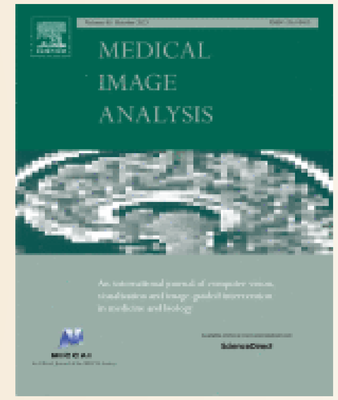
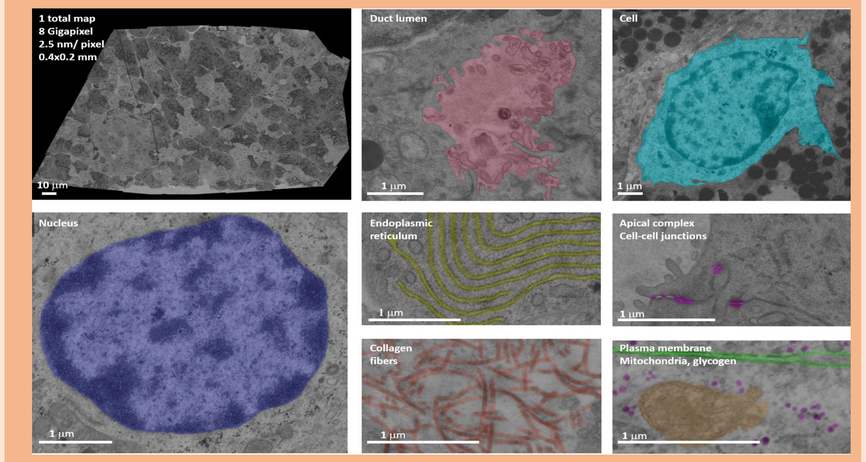
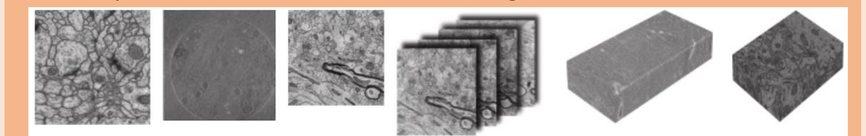


Electron Microscope(EM) analysis

- Electron microscopy (EM) is a widely used technique in life sciences for studying tissues, cells, subcellular components, and molecular complexes at the nanometer scale..



- Large-scale 2D EM of a section of human pancreas. Overview of a single dataset and snapshots from this total map at higher zoom showing several cellular, subcellular and macromolecular structures as indicated and annotated. (www.nanotomy.org).
- EM captures snapshots of biological samples as either two-dimensional (2D) images or three-dimensional (3D) volumes to analyze the ultrastructure of various organelles



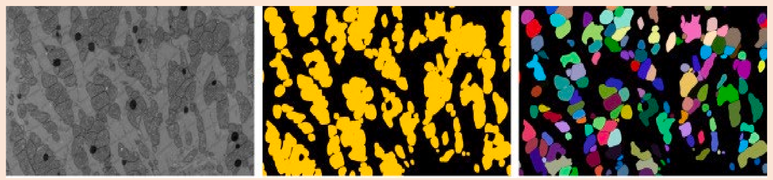
TEM 2D section	Cryo-ET 2D section	SEM 2D section	ssSEM volume - 2D sections	SBF-SEM volume	FIB-SEM volume
Ciresan et al. (2012)	Chen et al. (2017d)	Kasthuri et al. (2015)		Abdollahzadeh et al. (2021)	Lucchi et al. (2011)

Motivation and Scope

- Automated and faster image acquisition in EM a data avalanche (petabyte range per microscope/month) is becoming a reality. Due to this increase in the scale and acquisition speeds of imaging data, the need for automated EM segmentation is urgent.
- The following search query was used in Pubmed, Web of Science, and Google Scholar on words in titles (TI) only, restricted to 2017–2022: TI = ((electron microscopy OR EM) AND (segmentation OR semantic OR instance OR supervised OR unsupervised OR self-supervised OR semi-supervised)).

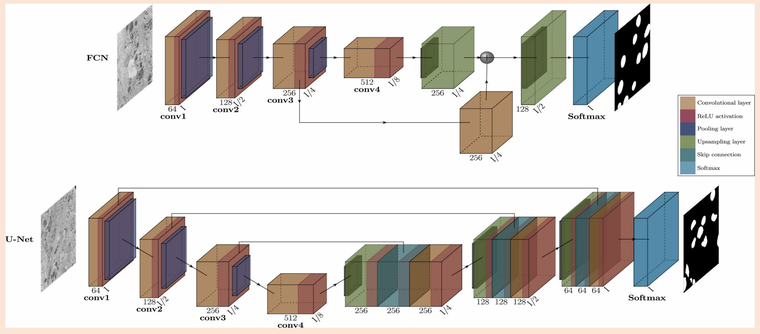
Semantic & instance segmentation

- Semantic segmentation is a pixel-level image analysis task that involves partitioning an image into distinct and coherent regions.
- Instance segmentation assigns to each pixel of the semantic class label a unique instance identity for each structure.



2D and 3D architectures

- Convolutional neural networks for 2D segmentation are either of FCN/U- Net type.



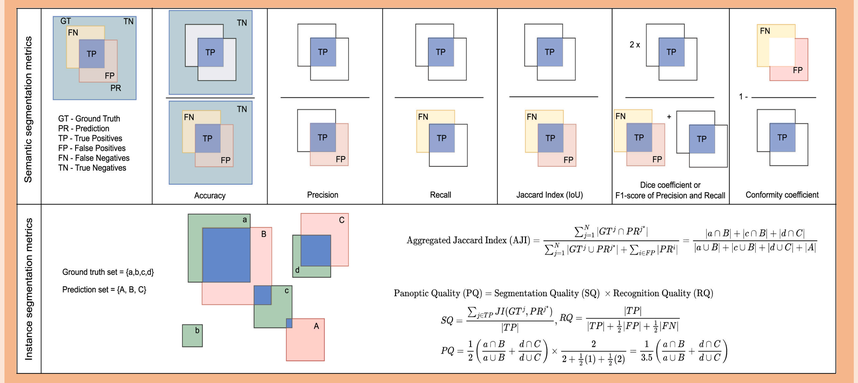
- For 3D datasets the first involves 2D segmentation of each image in the stack, followed by 3D reconstructions based on post-processing.
- The second approach is based on 3D CNNs, which can learn representations of volumetric data that include 3D spatial context.
- The third approach is graph analysis based on neural network predictions

Learning Approaches

- Supervised methods use labeled data to train models for pixel-wise segmentation in an end-to-end manner.
- Semi supervised learning is a combination of supervised and unsupervised learning. It uses both labeled and unlabeled data.
- Unsupervised- use unlabeled data to identify patterns or cluster them. In self-supervised learning, a model is trained on a dataset with labels that are automatically generated from the data itself.

Segmentation evaluation metrics

- For semantic segmentation, all ground truth connected components are considered as one object, and similarly all predicted connected components are treated as one object.
- Segmenting neuronal regions by partitioning images requires identifying areas based on membrane delineation and use the Rand Index (RI), Vrand, Vinfo, VOI, ARE, WE, PE as measures.
- Instance segmentation requires more detailed measures to quantify the segmentation mask accuracy along with the detection.



Summary and Conclusion

- The role of CNNs in large-scale cellular EM segmentation is described.
- End-to-end learning based on advanced CNN architectures using labeled data has achieved human-level accuracy in semantic segmentation tasks whereas the problem of instance segmentation still requires efforts, especially in the case of highly crowded structures.
- Semi-supervised and unsupervised methods that use data-driven methodologies play an important role.
- In addition to manual annotation, EM images can be labeled using specialized imaging modalities that target specific structures in the sample.
- We expect a shift towards more general-purpose segmentation models, using the large-scale networks and learning methods discussed in our review for extracting generic features in a task-independent manner.
- These features could allow the unsupervised discovery of new structures and regions of interest or could be adapted to specific supervised segmentation tasks.

This project has received funding from the Centre for Data Science and Systems Complexity at the University of Groningen, Netherlands, and sponsors from UMCG

For more details- https://doi.org/10.1016/j.media.2023.102920